A Comparison of Tactaid II+ and Adults with a Profound Hearing Impairment

Karyn L. Galvin, Gina Mavrias, Alessandra Moore, Robert S. C. Cowan,
Peter J. Blamey, and Graeme M. Clark

Objective: To evaluate and compare use of the Tactaid II+ and the Tactaid 7, in terms of speech perception, by adults with a hearing impairment.

Design: Eight adults used one device daily for approximately 10 wk and attended seven training sessions. Performance was measured with tests of phonetic contrast perception, closed-set vowel and consonant identification, word and phoneme recognition in monosyllabic word lists, word recognition in sentences and speechtracking rate. A questionnaire was also administered. The protocol was repeated with the alternative device.

Results: With each device, the group discriminated most phonetic contrasts at better-than-chance levels and demonstrated somewhat enhanced visual or auditory-visual perception when measured in terms of vowel identification, monosyllabic word recognition and speechtracking rate. An increase in speechtracking rate was also demonstrated for some individuals. Subjects generally reported little subjective improvement in speech perception and production, but were satisfied with the physical attributes of each device. Five of six subjects preferred the Tactaid 7.

Conclusions: The Tactaid II+ and the Tactaid 7 provided suprasegmental and segmental information, enabling the group to discriminate phonetic contrasts and improve their perception of some speech materials. No consistent advantage was found for either device, though most subjects preferred the Tactaid 7. Alternatives likely to provide a greater benefit to communication should be considered before a Tactaid fitting.

(*Ear & Hearing* 1999;20:471-482)

Researchers have explored a variety of alternatives and supplements to speechreading and standard hearing aids to improve the oral communication of adults with a profound hearing impairment. One supplemental approach is the provision of speech information through a tactile device (see, for

example, Levitt, Pickett, & Houde, 1980; Oller, 1995; Reed, Durlach, Delhorne, Rabinowitz, & Grant, 1989; Summers, 1992). During the last three decades a number of tactile devices have been released as commercial products, including the Mini-Fonator (Weisenberger, 1989), the Tactile Acoustic Monitor (Summers & Farr, 1989) and the Tacticon 1600 (Saunders, 1985). The most widely used, commercially available devices have been vibrotactile devices developed by Audiological Engineering Corporation*, these being: the Tactaid II; a subsequent version of this device, the Tactaid II+; and the more complex Tactaid 7. Other device options developed for people with a hearing impairment are multiple-channel cochlear implants (see, for example, Kessler, Osberger, & Boyle, 1997; Whitford et al., 1995) and speech-processing hearing aids (see, for example, Levitt, 1997; McDermott, Dean, & Dillon, 1999). A wealth of evaluative data is reported in the literature for these types of devices. It is important that commercially available tactile devices are also extensively evaluated, so that adequate information is available when device options are being considered.

Studies examining the use of Tactaids by adults with a hearing impairment have produced variable results. Plant (1989a) evaluated tactile-alone speech feature perception with the Tactaid II using a two-alternative, forced-choice format. The group of five subjects scored significantly above chance on subtests examining syllable number and stress pattern, vowel duration, vowel first and second formant, initial consonant voicing and various initial consonant manner contrasts. The group failed to score significantly more than chance level on the vowel second formant and initial nasal versus voiced fricative subtests.

In a study by Roger, Thornton, and Phillips (1992) 12 subjects had 2 wk of experience with the Tactaid II. A mean enhancement of around 13 words per minute (wpm) was reported for speechtracking when the Tactaid II was added to vision. No increase over vision-alone scores was shown on the BKB

CRC for Cochlear Implant Speech and Hearing Research, (K.L.G., G.M., A.M., R.S.C.C., G.M.C.), Melbourne, Australia; The Bionic Ear Institute (K.L.G., R.S.C.C., G.M.C.), Melbourne, Australia; Australian Hearing Services (G.M., A.M.), Sydney, Australia; and University of Melbourne (R.S.C.C., P.J.B., G.M.C.), Melbourne, Australia.

* Full details of the operation of these devices can be found in their respective manuals, which were available at the time of writing from Audiological Engineering Corporation, 35 Medford Street, Somerville, MA 02143, USA.

Sentence Test when key words were scored for the whole word correct or on consonant recognition when scored for the number of correct responses. A benefit from the Tactaid II was shown on environmental sound discrimination, but not on intonation discrimination.

Lynch, Eilers, Oller, Urbano, and Pero (1988) reported a significant increase in speechtracking rate for their subject when the Tactaid II was added to vision.

Waldstein and Boothroyd (1995) reported results for one subject who used the Tactaid 7 for 17 wk. Pretraining and post-training, the subject's tactile-alone scores on the closed-set Speech Pattern Contrast test were not above chance for vowel height, vowel place, final consonant voicing, consonant manner, consonant place, intonation or stress location contrasts. The score on the initial consonant voicing subtest pretraining, and the overall mean score pretraining and post-training, were significantly above chance. Scores with the Tactaid 7 plus vision were higher than vision-alone scores for the perception of initial consonant manner pretraining, as well as initial consonant voicing, final consonant manner and the overall mean score post-training. Scores with the Tactaid 7 were not higher than vision-alone scores for the perception of the other speech features, or for the recognition of monosyllabic words or words in sentences.

In their comparative Tactaid study, Osberger, Robbins, Todd, and Brown (1991) reported higher scores with the Tactaid 7, even though their subjects had more experience with the Tactaid II+. For one subject, discrimination scores were significantly higher with the Tactaid 7 for four out of five word pairs and speechtracking enhancement was 3 wpm with the Tactaid II+ compared with 8 wpm with the Tactaid 7. The second subject was assessed on closed-set contrasts of environmental sounds and words of varying syllable patterns, and scored 100% with the Tactaid 7 and 67% with the Tactaid II+.

Reed and Delhorne (1995) also evaluated subjects using the Tactaid II+ and the Tactaid 7. In their study, seven adults used the Tactaid 7 daily for between 2 and 4 yr. When the Tactaid 7 was added to vision, five subjects demonstrated significantly increased scores on each of two sentence tests and an average increase in speechtracking rate of roughly 5 wpm. In contrast, one subject demonstrated no improvement and an eighth subject withdrew after 5 mo. The three subjects with previous experience using the Tactaid II+ were also evaluated with that device. The mean enhancement was approximately 12 percentage points for words in sentences and roughly 6 wpm for speechtracking. For two subjects, the benefit demonstrated with the

Tactaid II+ was slightly greater than that shown with the Tactaid 7.

In summary, the studies in the literature have demonstrated that the Tactaid II/II+ and the Tactaid 7 provide phonetic information that can be used in the closed-set discrimination of some speech features, and may enhance vision-alone scores on sentence perception and speechtracking for some users. However, the superiority of one device over the other is unclear. In one study, the two subjects evaluated received a greater benefit from the Tactaid 7 (Osberger et al., 1991), whereas, in another study, two of the three subjects evaluated received a greater benefit from the Tactaid II+ (Reed & Delhorne, 1995). A number of the studies reviewed above concluded that, to more clearly compare the benefits available from the two devices, further research was required with a larger number of subjects, a wider range of evaluation materials and increased opportunity for subjects to learn to utilize the tactile information.

The main aim of the present study was to evaluate and compare use of the Tactaid II+ and the Tactaid 7, in terms of speech perception, by a group of adults with a hearing impairment. An additional aim was to compare the devices in terms of the users' subjective impression of device benefit and ease of use.

METHODS

Design

The study used an ABAB design, allowing for a balanced order of device use across subjects. During each period of device use, subjects attended seven once-per-week training sessions, followed by an evaluation session. Additional time was required when subjects were unavailable for some sessions and/or an evaluation was not completed in one session. As a result, the majority of the subjects did not complete the four periods of device use required in the ABAB design and the number of weeks taken to complete each period varied (refer to Table 1). The design was further affected by a lack of access to sufficient subjects, resulting in an unbalanced order of device use across subjects.

Devices

The Tactaid II+ consists of two vibrators on a wrist strap, and a speech processor with a microphone and a volume control. Bandpass filters measure energy in the incoming signal in the ranges 100 Hz to 1800 Hz and 1500 Hz to 7000 Hz. The energy measured in each band is used to

TABLE 1. Device used and length in weeks for each period of device use completed by each subject.

Subject	Period 1		Period 2		Period 3		Period 4	
	Device	Wk ^a	Device	Wk	Device	Wk	Device	Wk
S1	Tactaid 7	10	Tactaid II+	10	Tactaid 7	10	Tactaid II+	15
S2	Tactaid 7	13	Tactaid II+	10	Tactaid 7	18		
S3	Tactaid 7	10	Tactaid II+	13	Tactaid 7	10		
S4	Tactaid 7	10	Tactaid II+	10	Tactaid 7	10		
S5	Tactaid 7	10	Tactaid II+	11	Tactaid 7	15 ^b		
S6	Tactaid 7	10	Tactaid II+	8	Tactaid 7	8	Tactaid II+	8
S7	Tactaid II+	15	Tactaid 7	17 ^c				
S8	Tactaid II+	9	Tactaid 7	9				

^a Number of weeks taken to complete seven training sessions and evaluation protocol.
^b Device not used during 1 mo holiday within the 15 wk.
^c Ill for 1 mo within the 17 weeks.

amplitude modulate a 250 Hz carrier tone presented to the relevant vibrator. The Tactaid II+ is designed to provide temporal, intensity and spectral information by altering the active vibrator and through changes in the presence and strength of vibrations. The low-frequency channel provides information about the speech envelope, such as cues to the intensity and duration of syllables and phonemes. The high-frequency channel provides information about the presence of high-frequency speech sounds, such as fricatives and some unvoiced stops.

The Tactaid 7 consists of a speech processor with a volume control, and a sleeve-covered row of seven vibrators. The vibrators are most often worn on the sternum or the abdomen. Users can choose between a processor-mounted or lapel microphone. The acoustic spectrum from 200 Hz to 7000 Hz is divided among seven channels, with crossover frequencies at 380 Hz, 500 Hz, 700 Hz, 1245 Hz, 1680 Hz, and 3180 Hz. The processor uses a zero-crossing analysis circuit to establish the two main spectral peaks in the incoming signal. The peaks represent the first formant and second formant for vowels, or the peak energy in the bands 200 Hz to 1250 Hz and 800 Hz to 7000 Hz for consonants. Only two vibrators are active at any given time, and the strength of the stimulus depends on the amplitude of the input signal. The presentation of the waveform envelope provides cues to the intensity and duration of syllables and phonemes. The Tactaid 7 is designed to provide more spectral information than the Tactaid II+. Vowel formant information is provided via stimulation on particular vibrators. Consonant discrimination may be improved through, for example, the use of cues to the presence of high-frequency information indicated by activation of channels 6 and 7, or cues to nasal resonances presented on the lower channels.

Subjects

Subjects were selected from the adult client base of Australian Hearing Services[†] using the following criteria: a 3-frequency average pure-tone threshold greater than 80 dB HL in the better ear; dissatisfaction with current communication performance; a commitment to participate in weekly sessions and to use the devices daily; and no prior experience with multichannel tactile devices. Table 2 presents the subject details. To maximise the number of subjects, the prior experience condition was waived for subject 1 (S1) and S2, who had some previous experience with the Tactaid II. S8 used sign language as her main mode of communication, but communicated orally with the clinicians during this study. All other subjects used only oral communication at all times. Subject 3, S4, S5, and S6 were fitted with hearing aids and wore these during the study. Subject 1, S2, S7, and S8 were not fitted with hearing aids and reported finding them to be of no benefit. As shown in Table 1, S1, S2, S3, S4, S5, and S6 initially used the Tactaid 7, whereas S7 and S8 initially used the Tactaid II+.

Training Sessions

Training sessions were designed to familiarize the subject with the tactile device and to provide guidance and experience in interpreting the tactile signal. During each session, 15 minutes were spent on each of phoneme-level and word-level tasks using tactile and auditory information. For those subjects without hearing aids, visual information was provided at the discretion of the clinician to supplement the tactile information. An additional 25 minutes were spent on each of sentence-level and conversational-level tasks using tactile, auditory and visual information. In the first two sessions with each

[†] An Australian Government statutory authority providing services to pensioners and children with a hearing impairment.

TABLE 2. Subject details.

Subject	Age	Etiology	Onset ^a mo	Prior Tactile Device Use (Duration in Yr)	PTA ^b	Aided Levels (250, 500, 1k, 2k Hz) ^c
S1	47	Mastoiditis	8	Minivib (3), ^d Tactaid II: some situations (4)	NR ^e	Not aided
S2	72	Meniere's	65	Tactaid II: inconsistent use (3)	115 at 500	Not aided
S3	62	Diabetes	28	None	92	R: NT, ^f 76,76,NR/L: NT,61,65,64
S4	69	Head trauma	55	None	110	R: NR,57,62,60/L: 76,65,41,41
S5	75	Otosclerosis	35	None	107	R: 80,65,45,50/L: 80,65,55,40
S6	77	Otosclerosis	18	None	120	R: 55,45,45,50/L: not aided
S7	76	Unknown	12	None	NR	Not aided
S8	30	Rubella	6	Minivib: occasional use (9)	NR	Not aided

^a Approximate age in years at onset of profound hearing loss.^b Pure-tone average: average unaided hearing level at 500 Hz, 1000 Hz, and 2000 Hz in the better ear in dB HL re ANSI (1989).^c Aided hearing levels in dB SPL re μ Pa.^d Single-channel vibrotactile device.^e No response at the limits of the audiometer.^f Not tested.

device, some time was spent on basic tactile-alone tasks, such as the perception of sound intensity and syllable patterns.

Evaluation

Performance was measured with tests of phonetic contrast perception, closed-set vowel and consonant identification, phoneme and word recognition in monosyllabic word lists, word recognition in sentences, and speechtracking rate. For all materials, subjects were seated 1.5 meters from the sound source in a well-lit, quiet room. The long-term average presentation level of 70 dBA was monitored using a sound-level meter.

The phonetic contrast test employed an ABx presentation format, which was designed to reduce the effects of prior experience and training on subject performance (Plant, 1989a). The 12 subtests of 24 items were presented on video tape in the tactile-alone condition. For each item, two words (three for subtest 12) were presented that differed with respect to the relevant phonetic contrast. One word was then repeated as the stimulus. Table 3 presents the phonetic contrast examined in each subtest.

The closed-set vowel test contained four randomized presentations of 11 vowels in each list. The closed-set consonant test contained four randomized presentations of 12 consonants in each list. The lists were presented live-voice in the auditory-alone and tactile-auditory conditions. Note that S1, S2, S7, and S8 did not wear hearing aids and were unable to detect the auditory component in any stimuli. These subjects did not complete assessments in the audi-

tory condition, and the relevant chance score was assumed in the analysis of results.

Phoneme and word recognition was evaluated using the open-set Consonant-Nucleus-Consonant (CNC) Words test (Peterson & Lehiste, 1962). Each list consisted of 50 monosyllabic words and the responses were scored for the number of words correct and the number of phonemes correct. Word recognition in sentences was evaluated using the open-set Speech Intelligibility Test (SIT) Sentences (Magner, 1972). Each list contained 16 sentences

TABLE 3. Contrast examined in each subtest of the phonetic contrast test.

Subtest	Detail of Phonetic Contrast
Syllable number & Stress I	Syllables joined by /b/, e.g., BA vs. baBA
Syllable number & Stress II	Syllables joined by /m/, e.g., maMama vs. MA
Vowel duration I	In /stop-vowel-stop/ frame, e.g., bead vs. bid
Vowel duration II	In /stop-vowel-voiced continuant/ frame, e.g., keen vs. kin
Vowel 1 st & 2 nd formant	In variety of consonant frames, e.g., pip vs. pup, heat vs. heart
Vowel 2 nd formant	In variety of consonant frames, e.g., me vs. moo, tap vs. top
Consonant voicing	Initial position, e.g., beat vs. peat, chin vs. gin
Nasal/stop	Initial nasal vs. voiced stop, e.g., meat vs. beat, nark vs. dark
Fricative/stop	Initial position, e.g., feet vs. peat, vat vs. bat
Stop/affricate	Initial alveolar stop vs. postalveolar affricate, e.g., tick vs. chick, dot vs. jot
Nasal/fricative	Initial nasal vs. voiced fricative, e.g., nip vs. zip, mat vs. vat
High-frequency consonants	Initial /s/ vs. /t/ vs. /st/, e.g., sag vs. tag vs. stag

with 80 key words per list and the responses were scored for the number of key words correct. The word and sentence tests were presented on video tape in the auditory-visual and tactile-auditory-visual conditions. The order of conditions and the test lists used were balanced across subjects and devices. The tests of vowel and consonant identification, the CNC Words test and the SIT Sentences were administered in an evaluation session at the end of each period of device use.

Speechtracking was used as both an evaluation and a training task (De Filippo & Scott, 1978). In each training session, subjects completed 5 minutes of speechtracking in each of the auditory-visual and tactile-auditory-visual conditions. The order of conditions was balanced across sessions, subjects and devices. A children's novel, *Misery Guts* (Gleitman, 1991), was the speechtracking text used with S1, S3, S5, S6, and S8 in all sessions. S7 found this text very difficult to track in sessions 1 to 3 of Period 1. In subsequent sessions *COMMTRAC—Modified Connected Discourse Tracking Exercises for Hearing Impaired Adults* (Plant, 1989b) was used as the text with this subject. *COMMTRAC* was also used with S2 in sessions 1 to 3 of Period 1 and with S4 in all sessions of Period 1 and in sessions 1 and 2 of Period 2.

Questionnaire

Because of the unavailability of S5 and S7, the questionnaire was completed only by S1, S2, S3, S4, S6, and S8. Subjects were asked to indicate whether they were very satisfied, satisfied, dissatisfied or very dissatisfied with the size, looks, comfort/convenience, placement, reliability and battery life of each device, and the overall benefit to themselves from each device. Subjects also were asked to indicate whether they had experienced a significant improvement, some improvement, no change, or a deterioration in relation to their speech understanding, voice quality, and voice level while using each device. The responses to the voice quality and level questions were based on feedback from those who communicated with the subjects. The options on each scale were allocated a score (4 for very satisfied or significant improvement and 1 for very dissatisfied or deterioration) so that responses could be rated. Some items on the questionnaire were grouped into categories to produce a rating for each device in terms of speech perception (one item), speech production (two items), physical attributes (six items: size, reliability, battery life, etc.), and overall benefit (one item).

Figure 1. Mean scores for eight subjects, obtained in the tactile-alone condition with the Tactaid II+ and the Tactaid 7 on the subtests of the phonetic contrast test. Scores have been adjusted for the effects of guessing, using the equation $c = (r - g) / (100 - g) * 100$ (where c = corrected score in %; r = raw score in %; g = expected guessing score in % [33.3 for high-frequency consonant subtest, 50 for all other subtests]). Dotted line shows the 95% confidence limit for scores significantly above chance (based on random guessing by every subject on every trial and estimated using the binomial distribution for $p = 0.5$ or 0.33 and 192 trials per subtest, i.e., 8 subjects x 24 trials).

RESULTS

Phonetic Contrasts

Figure 1 presents the group scores with each device on the subtests of the phonetic contrast test. Scores are averaged across the eight subjects. Note that scores were obtained in the tactile-alone condition and are corrected for guessing. The dotted line represents the 95% confidence limit for corrected scores greater than chance, which was calculated using the binomial approximation of Thornton and Raffin (1978) and $N = 192$ (i.e., 8 subjects by 24 items). Results with the Tactaid II+ were obtained from S8 before the start of training and from all other subjects after one period of training with the device. Results with the Tactaid 7 were obtained from S7 after one period of training with the device, from S8 after half a period of training and from all other subjects after two periods of training with the device. As shown, scores with the Tactaid II+ were significantly above chance ($p < 0.05$) on all subtests except the vowel second formant subtest. Scores with the Tactaid 7 were significantly above chance ($p < 0.05$) on all subtests except the vowel second formant and consonant voicing subtests.

To compare performance with the two devices across subjects and subtests, an Analysis of Vari-

ance was conducted on the scores of all individuals on all subtests. The factors in the analysis were device, subtest and subject[‡]. The main effect of device was significant ($F(1,77) = 7.3$; $p = 0.009$), indicating that, for this group, performance on phonetic contrast perception with the Tactaid II+ was slightly better than performance with the Tactaid 7. The main effect of subtest was also significant ($F(11,77) = 6.7$; $p < 0.001$), indicating that the group score was higher on some subtests. The Tukey Simultaneous Test indicated that the mean scores (collapsed across eight subjects and two devices) on the syllable number/stress I and vowel duration I subtests were significantly ($p < 0.05$) greater than the mean scores on the vowel second formant, consonant voicing, stop/affricate, nasal/fricative and high-frequency consonants subtests. Results further indicated that the mean score on the vowel duration II subtest was significantly greater than the mean scores on the vowel second formant, consonant voicing and high-frequency consonants subtests. The main effect of subject was not significant ($F(7,77) = 1.6$; $p = 0.16$), indicating that performance across subjects was similar. No significant interaction effects were found (device by subject: $F(7,77) = 0.59$; $p = 0.76$; device by subtest: $F(11,77) = 0.81$; $p = 0.63$; subject by subtest: $F(77,77) = 1.1$; $p = 0.35$). The absence of a device by subject or device by subtest effect indicates that the small advantage found for the Tactaid II+ was not driven only by the scores of particular subjects or by scores on particular subtests.

Speech Perception Enhancement

The speech perception enhancement provided by the two devices was evaluated using the results of all eight subjects obtained in Period 1 and Period 2.

Figure 2 presents the group scores for the identification of vowels and consonants with each device. Scores were obtained in the auditory and tactile-auditory conditions and are collapsed across eight the subjects. Figure 3 presents the group scores for the perception of CNC words, phonemes in CNC words and key words in SIT sentences with each device. Scores were obtained in the auditory-visual and tactile-auditory-visual conditions and are collapsed across the eight subjects. To evaluate and compare the enhancement provided by the two devices, an Analysis of Variance was conducted for each material on the scores of all subjects. The factors in the analyses were condition, device and subject. The resulting F-statistics and p -values of

[‡] It should be noted that the conclusions of significance made for analyses which include subject as a fixed effect can be applied to the present subject group only.

Figure 2. Mean vowel confusion and consonant confusion scores for eight subjects. Scores were obtained in the auditory and tactile-auditory conditions with the Tactaid II+ and the Tactaid 7.

the main effects and the interaction effects are presented in Table 4. The effects that are relevant to the questions posed in this study are the condition effect, which indicates whether perception was enhanced when a tactile device was used, and the condition by device interaction effect, which indicates whether any enhancement provided varied across the devices. A significant condition effect was found for the perception of vowels and CNC words, indicating that group scores increased on these materials only when tactile information was provided. No significant condition by device interaction effects were found, indicating that the level of enhancement provided by the two devices was similar.

Figure 4 presents the mean speechtracking rates in the auditory-visual and tactile-auditory-visual conditions for each training session in Period 1,

Figure 3. Mean Consonant-Nucleus-Consonant (CNC) Word, CNC Phoneme, and Speech Intelligibility Test (SIT) Sentence scores for eight subjects. Scores were obtained in the auditory and tactile-auditory conditions with the Tactaid II+ and the Tactaid 7.

TABLE 4. F-statistics and *p*-values for main effects and interaction effects of the analyses of variance conducted for each material on the scores of all eight subjects with each device.

Effect		Vowels	Consonants	CNC Words	CNC Phonemes	SIT Sentences	Speechtracking
Condition ^a	F	31.3	2.3	7.6	5.1	2.1	30.4
	<i>p</i>	<0.001	0.17	0.028	0.059	0.19	<0.001
Device ^a	F	14.9	5.8	0.04	0.7	1.9	11.0
	<i>p</i>	0.006	0.047	0.9	0.44	0.21	0.001
Subject ^b	F	152.3	59.3	64.4	54.0	46.5	47.7
	<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cond × dev ^a	F	<0.01	0.6	0.2	0.4	0.5	0.02
	<i>p</i>	0.99	0.48	0.65	0.53	0.52	0.89
Cond × subj ^b	F	3.5	0.7	0.77	1.3	0.4	1.1
	<i>p</i>	0.059	0.65	0.63	0.38	0.86	0.35
Dev × subj ^b	F	2.2	0.9	2.4	0.99	1.9	6.1
	<i>p</i>	0.16	0.56	0.14	0.5	0.21	<0.001
Cond × dev × subj ^b	F						0.31
	<i>p</i>						0.95

^a Degrees of freedom (1,191) for speechtracking and (1,7) for all other materials.
^b Degrees of freedom (7,191) for speechtracking and (7,7) for all other materials.
Boldface type indicates effects that reached significance at $\alpha = 0.05$.

Period 2 and Period 3 with the Tactaid 7, the Tactaid II+ and the Tactaid 7, respectively. Note that, for the illustrative purposes of this figure only, rates are collapsed across the first six subjects, who completed this order of device use. The results of S7 and S8 were not included as they completed the alternative order of device use. To evaluate and compare the enhancement provided by the two devices, an Analysis of Variance was conducted on the speechtracking rates of all eight subjects in all of the 14 training sessions in Period 1 and Period 2. The factors in the analysis were condition, device and subject, with session number as a covariate. The resulting F-statistics and *p*-values of the main effects and the interaction effects are included in Table 4. A significant condition effect was found, indicating that the

Figure 4. Mean speechtracking rate for each training session. Rates are collapsed across S1 to S6 and were obtained in the auditory-visual and tactile-auditory-visual conditions using the Tactaid 7 in Period 1, the Tactaid II+ in Period 2, and the Tactaid 7 in Period 3.

group speechtracking rate increased when tactile information was provided. No significant condition by device effect was found, indicating that the level of enhancement provided by the two devices was similar.

Figure 5 presents the mean speechtracking rates with each device for individual subjects. Rates for S1, S2, S3, and S4 are presented in Figure 5a and rates for S5, S6, S7, and S8 are presented in Figure 5b. Rates were obtained in the auditory-visual and tactile-auditory-visual conditions with each device and are collapsed across the seven sessions of Period 1 or Period 2. To evaluate and compare the enhancement provided by the two devices for individuals, an Analysis of Variance was conducted for each subject on the speechtracking rates in the 14 sessions of Period 1 and Period 2. The factors in the analysis were condition and device, with session number as a covariate. The resulting F-statistics and *p*-values for the main effects and the interaction effects are presented in Table 5. A significant condition effect was found for S1, S2, S3, S5, and S7, indicating that the speechtracking rate increased for these subjects when tactile information was provided. The mean increase in rate ranged from 5.1 to 11.4 wpm with the Tactaid II+ and from 3.4 to 10.4 wpm with the Tactaid 7. No significant condition by device interaction effects were found, indicating that, for each individual, the level of enhancement provided by the two devices was similar.

Questionnaire

In terms of speech perception, most subjects reported no change to their speech understanding with the Tactaid II+; the exceptions were S2 and S6, who reported some improvement. S3, S4, and S8

Figure 5. A) Mean individual speechtracking rates for S1 to S4, obtained in the auditory-visual and tactile-auditory-visual conditions with each device. Rates are collapsed across the seven sessions of Period 1 or Period 2. B) Mean individual speechtracking rates for S5 to S8, obtained in the auditory-visual and tactile-auditory-visual conditions with each device. Rates are collapsed across the seven sessions of Period 1 or Period 2.

also reported no change with the Tactaid 7; though S1 and S2 reported a significant improvement and S6 reported some improvement with this device. The

mean ($N = 6$) ratings were 2.3 for the Tactaid II+ and 2.8 for the Tactaid 7.

In terms of speech production, subjects generally reported no improvement with the Tactaid II+ or the Tactaid 7. However, S6 and S8 did report some improvement in voice level with both devices. The clear exception was S1, who reported a deterioration in voice level and quality with the Tactaid II+, but some improvement in voice level and a significant improvement in voice quality with the Tactaid 7. The mean ($N = 6$) ratings were 2.0 for the Tactaid II+ and 2.4 for the Tactaid 7.

In terms of physical attributes, subjects were mostly satisfied, and occasionally very satisfied, with the specified attributes of the Tactaid II+ and the Tactaid 7. Interestingly, ratings for specific attributes varied across subjects. The comfort/convenience of the Tactaid 7 was the only exception, being the one attribute all subjects were satisfied with. The mean ($N = 6$) ratings were 2.8 for the Tactaid II+ and 2.9 for the Tactaid 7.

In terms of overall benefit, only S8 was satisfied with the Tactaid II+, most subjects were dissatisfied and S4 was very dissatisfied. Responses were varied for the Tactaid 7, with S4 very dissatisfied, S3 and S6 dissatisfied, S2 and S8 satisfied and S1 very satisfied. The mean ($N = 6$) ratings were 1.9 for the Tactaid II+ and 2.4 for the Tactaid 7.

Only S1 rated one device, the Tactaid 7, as superior on nearly every item. In contrast, the other subjects rated the devices equally on all (S4, S6, and S8) or most (S2 and S3) of the questions. The exceptions were that S2 rated the Tactaid 7 more highly for speech perception and S3 rated the Tactaid 7 more highly for physical attributes (preferring the comfort/convenience and placement of this device). In contrast, S2 rated the Tactaid II+ more highly on physical attributes (preferring the size of this device). All subjects, except S8, preferred the Tactaid 7 over the Tactaid II+. The reasons given generally related to the complexity and clarity of the tactile signal. For example, S6 reported "more vibrations" and a "clearer signal," S4 reported "more

TABLE 5. F-statistics and p -values for main effects and interaction effects of the analysis of variance conducted for each subject on auditory-visual and tactile-auditory-visual speechtracking rates.

Effect		S1	S2	S3	S4	S5	S6	S7	S8
Condition	F	14.5	8.0	5.5	1.7	4.9	0.79	5.6	2.1
	p	0.001	0.01	0.028	0.20	0.037	0.38	0.027	0.16
Device	F	9.4	1.3	3.3	1.8	0.3	0.9	0.95	0.01
	p	0.005	0.26	0.08	0.19	0.61	0.36	0.34	0.92
Cond $\times$ dev	F	0.1	0.5	0.05	0.01	0.2	1.1	0.3	0.4
	p	0.78	0.49	0.83	0.91	0.66	0.31	0.62	0.52

Rates were obtained with each device in the seven sessions of Period 1 or Period 2. Degrees of freedom = (1,23) for each effect.

Boldface type indicates effects that reached significance at $\alpha = 0.05$.

quality for hearing speech" and S1 commented that the device was "more effective." In contrast, comments made about the Tactaid II+ were generally negative. For example, S3 reported that the device "did not provide sufficient information. . . electrodes were too close together" and S4 reported that "half the time one (vibrator) would come on but the other wouldn't come on at all." S8 preferred the Tactaid II+ for the comfort of the wrist placement.

DISCUSSION

This study evaluated and compared the phonetic contrasts perceived with the Tactaid II+ and the Tactaid 7 and the speech perception enhancement provided by the two devices. Although relatively low, scores for the discrimination of the majority of contrasts examined were significantly greater than chance level, with a slight advantage to the Tactaid II+ over the Tactaid 7 across contrasts. The group demonstrated minimal enhancement of the perception of vowels and monosyllabic words and speechtracking rate with each device, but no enhancement of the perception of consonants, phonemes in monosyllabic words or words in sentences. An increased speechtracking rate was also demonstrated with each device by some individuals. Across materials, a similar level of enhancement was provided by both devices. The subjects were generally fairly negative regarding the subjective impression of benefit gained from each device, but were generally satisfied with the physical attributes of the devices. Subject preference was for the Tactaid 7.

Previous findings with the Tactaid II or the Tactaid II+ have been similar to the present results for phonetic contrast perception (Plant, 1989a), but, in some cases only, somewhat better for the perception of words in sentences (Reed & Delhorne, 1995) and speechtracking (Roger et al., 1992). Previous findings with the Tactaid 7 have been similar to those for the present group on speechtracking (Osberger et al., 1991; Reed & Delhorne, 1995), but variable across other materials. One study failed to demonstrate any improvement in the perception of phonetic contrasts or words in sentences with the Tactaid 7 (Waldstein & Boothroyd, 1995). In contrast, another study reported a significant improvement in the perception of words in sentences when the Tactaid 7 was used (Reed & Delhorne, 1995).

Clearly, there is variability in the results with the Tactaid II+ and the Tactaid 7 across studies. Although it is not possible to determine the balance of factors contributing to this variation, it is important to note that training, subject and evaluation differences, and, most particularly, the small samples

involved limit the cross-study comparisons that can be made.

The Tactaid II+ and the Tactaid 7 appear to have provided the present group with both segmental and suprasegmental speech information. The enhancement of speechtracking rate and the relatively high scores on the subtests contrasting vowel duration and syllable number and stress pattern subtests suggest that subjects were gaining suprasegmental information from the tactile signal. However, even minimal aided hearing allows access to suprasegmental information, so those subjects with hearing aids would have found the tactile information redundant if the devices were supplying suprasegmental information only. Such a pattern was not evident, with S3 and S5 demonstrating an increased speechtracking rate with each device, despite evidence of useful aided hearing, such as mean auditory-alone consonant recognition scores of 21% and 62%, respectively. The group's above-chance scores on the vowel first and second formant subtest, the various consonant manner subtests and, for the Tactaid II+, the consonant voicing subtest also suggest that tactile segmental information was being used by the subjects. However, the relatively low scores achieved indicate that the information was either difficult to perceive consistently or difficult to perceive in some contexts. What the results do not indicate is exactly what segmental information the devices provided.

The Tactaid 7 was developed from the Tactaid II+ and provides information on five additional channels. Despite this, the present results failed to demonstrate an advantage for the Tactaid 7 and, in fact, demonstrated a small advantage for the Tactaid II+ on the phonetic contrast test. Previous comparative studies have reported some small differences in the enhancement provided by the two devices, though the direction of the difference has varied. Osberger et al. (1991) reported superior performance with the Tactaid 7 for one subject evaluated on word pair discrimination and speechtracking and a second subject evaluated on tactile-alone contrasts of environmental sounds and syllable pattern. In contrast, Reed and Delhorne (1995) reported that two of their three subjects demonstrated slightly greater enhancement with the Tactaid II+ for the perception of key words in sentences and speechtracking.

Given the unbalanced order of device use, it is necessary to examine whether order effects may have obscured any advantage to the Tactaid 7 in the present results. To this end, the Analyses of Variance described previously were repeated, using the scores of the six subjects who completed three periods of device use, using the Tactaid 7 in Period 1, the Tactaid II+ in Period 2 and the Tactaid 7 in Period

3. The results of S7 and S8 were not included as they did not complete a third period of device use. No significant device by condition interaction effects were found ($F(2,10) \leq 2.0$, $p \geq 0.19$), indicating that the level of enhancement provided by the tactile signal was similar across the three periods. Thus, the level of enhancement provided by the Tactaid 7 did not increase with further training and experience and, even with a second period of use of the Tactaid 7, there was no greater enhancement provided by this device than the Tactaid II+.

To access the extra information provided by the five additional channels of the Tactaid 7, subjects would need to be able to discriminate between the channels. No subject scored above chance on the vowel second formant subtest, in which formant changes were presented as a change in the active vibrator. This result suggests that subjects had difficulty distinguishing among the channels. One subject also reported difficulty in maintaining close contact between the skin and all seven vibrators. The advantage for the Tactaid II+ on the phonetic contrast test was not carried across to the other evaluation materials. The minimal advantage for the simpler device may have existed only in the closed-set, tactile-alone context.

Given the results obtained in this study, consideration should be given to factors that may have limited performance with the tactile information. Insufficient training and experience has been raised by many authors as a factor limiting performance with tactile devices (Galvin, Cowan, Sarant, Blamey, & Clark, 1993; Oller, 1995; Plant, 1995; Reed et al., 1989). However, the above analysis found no increase in enhancement from the Tactaid 7 with further training and experience. The lack of increase in enhancement provided by either device was further demonstrated by the relationship between the enhancement of speechtracking rate provided by a particular device and the number of training sessions completed with that device. A one-tailed Pearson's correlation was calculated for each subject with each device across all periods completed by the subject (refer to Table 1). The only subject to demonstrate a significant increase in enhancement with further training was S5 with the Tactaid 7 ($r = 0.63$, $df = 12$, $p < 0.05$). No other significant correlations were found for the Tactaid 7 ($r \leq 0.21$, $df = 12$, $p > 0.05$ for S1, S2, S3, S4, and S6; $r \leq 0.02$, $df = 5$, $p > 0.05$ for S7 and S8) or the Tactaid II+ ($r \leq 0.2$, $df = 12$, $p > 0.05$ for S1 and S6; $r \leq 0.63$, $df = 5$, $p > 0.05$ for S2, S3, S4, S5, S7, and S8). Two previous studies also examined performance with the Tactaid 7 with further training and/or experience, and failed to demonstrate any improvement. Waldstein and Boothroyd (1995) pro-

TABLE 6. Correlations for the level of speechtracking enhancement with each device and various subject characteristics.

Subject Characteristic	Correlation		Critical Value (1-tail, $\alpha = 0.05$)
	TacII+	Tac7	
No hearing aids	+0.47 ^a	+0.58 ^a	0.62 ($N = 8$)
Auditory-visual speechtracking rate	-0.58 ^b	-0.50 ^b	0.62 ($N = 8$)
Previous experience with Tactaid II	+0.75 ^a	+0.39 ^a	0.62 ($N = 8$)
Speech perception rating	0.00 ^c	+0.80 ^c	0.73 ($N = 6$)
Overall benefit rating	-0.17 ^c	+0.74 ^c	0.73 ($N = 6$)

^a Point-Biserial Correlation.

^b Pearson's Correlation.

^c Spearman Rank Order Correlation.

vided their subject with 78 hr of training over 13 wk, yet they recorded no pretraining to post-training improvement on the tactile-alone perception of phonetic contrasts or the tactile-plus-visual perception of phonetic contrasts, monosyllabic words, or key words in sentences. The seven subjects of Reed and Delhorne (1995) used the Tactaid 7 daily for between 2 and 4 yr, yet no trend for increased enhancement of the perception of words in sentences or speechtracking rate was evident in their evaluations over time.

The failure to demonstrate increased enhancement with further training suggests that the limited speech perception enhancement shown by the present group was more likely due to subject characteristics and/or the amount of information provided by the two devices than to lack of training or experience. The inter-subject variation in speechtracking enhancement is further indication of the influence of subject characteristics. Table 6 presents correlations for the relationship between various subject characteristics and the enhancement of speechtracking with each device. Increased speechtracking enhancement was positively correlated with the absence of hearing aids, previous experience with the Tactaid II and, for the Tactaid 7 only, the rating given for changes to speech understanding and overall benefit from the device. Increased speechtracking enhancement was negatively correlated with auditory-visual speechtracking rate and, for the Tactaid II+ only, the overall benefit rating. The only factors to be significantly ($p < 0.05$) correlated with the speechtracking enhancement provided by the Tactaid 7 were the questionnaire ratings. The only factor to be significantly correlated with the speechtracking enhancement provided by the Tactaid II+ was previous experience with the Tactaid II. Interestingly, this last result is in contrast to the suggestion above that further training and experience did not increase speechtracking enhancement from either device. Other subject characteristics that were not assessed also may be relevant; for example, it is

possible that subjects varied in their ability to recognize the speech information contained in the tactile signal and/or to integrate this information with that gained through other modalities. Given the minimal levels of enhancement that appear to be provided by the devices, any information enabling clinicians to gauge the potential for individual users to benefit from a Tactaid before device fitting would be particularly useful. Studies involving larger, more homogenous subject groups, which were controlled for characteristics considered to be potentially relevant, will be more likely to identify important relationships.

The questionnaire results were fairly consistent with the evaluation results. The low ratings for changes to speech perception reflected the minimal levels of enhancement demonstrated on only some materials. As most justifications of device preference related to the complexity and clarity of the signal, rather than improved speech understanding, the preference of most subjects for the Tactaid 7 did not contradict the test results. The real or subjective impression of advantage provided by the Tactaid 7 was not assessed by the evaluation materials nor adequately explored by the questionnaire. Determining the source of this benefit, perhaps through evaluation of environmental sound perception and more detailed questionnaires, may clarify the potential advantage for the Tactaid 7. The question would then remain if such an advantage outweighed the cost difference between the Tactaid II+ and the more complex Tactaid 7.

The minimal level of enhancement of speech perception demonstrated by this trained and experienced group suggests that options other than a Tactaid should be considered to improve the communication of adults with a profound hearing loss. Firstly, access to and use of auditory and visual information should be maximized through the provision of the best possible binaural hearing aid fitting and appropriate communication training. If communication is not improved to a satisfactory level, cochlear implantation should be discussed, as the enhancement of speech perception from an implant is likely to exceed that reported for either Tactaid in the present and previous studies (Blamey et al., 1996). The pros and cons of implantation need to be carefully considered with each individual, as this option may be unsuitable for personal, medical or audiological reasons. After these steps are taken, the fitting of a Tactaid may be appropriate for some adults. At this stage, the choice between a Tactaid II+ or a Tactaid 7 can only be based on cost and user preference.

In conclusion, the group gained suprasegmental and segmental information from the Tactaid II+ and the Tactaid 7, which enabled them to perceive

phonetic contrasts and enhance their perception of monosyllabic words and speechtracking, but not phonemes in words or key words in sentences. A small advantage was found for the Tactaid II+ in phonetic contrast perception, but there was no evidence of greater enhancement of speech perception with one device than the other, though five out of six subjects preferred the Tactaid 7. The group generally reported little or no subjective impression of improvement in speech perception or speech production when using either device, but five out of six subjects preferred the Tactaid 7. The minimal enhancement of speech perception demonstrated suggests that other options to improve communication should be considered before the fitting of a Tactaid.

ACKNOWLEDGMENTS:

The time and effort contributed by the subjects in this study are gratefully acknowledged. Dr. Karen Iler Kirk and Dr. Arthur Boothroyd completed a number of detailed and extensive reviews that significantly strengthened and clarified the manuscript. Anne Lu provided technical support, and Dr. Peter Busby contributed to the statistical analysis. The study was funded through the generosity of the Commonwealth of Australia, Department of Industry, Science and Tourism through their funding of the Cooperative Research Centres Program. The contribution of the parties to the Cooperative Research Centre for Cochlear Implant, Speech and Hearing Research is acknowledged, in particular the Bionic Ear Institute, University of Melbourne's Department of Otolaryngology and Australian Hearing Services. The Tactaid devices were provided by Australian Hearing Services through the Hearing Services Program of the Commonwealth Government.

Address for correspondence: Karyn L. Galvin, BSc,DipAud, MAudSA(CC), 384-388 Albert St., East Melbourne 3002, Australia.

Received June 19, 1997; accepted August 10, 1999

REFERENCES

- American National Standards Institute (1989). *Specifications for audiometers (Standard S3.6)*. New York: American National Standards Institute.
- De Filippo, C. L., & Scott, B. L. (1978). A method for training and evaluating the reception of ongoing speech. *Journal of the Acoustical Society of America*, 63, 1186-1192.
- Galvin, K. L., Cowan, R. S. C., Sarant, J. Z., Blamey, P. J., & Clark, G. M. (1993). Factors in the development of a training program for use with tactile devices. *Ear and Hearing*, 14, 118-127.
- Gleitzman, M. (1991). *Misery Guts*. Sydney: Pan.
- Kessler, D. K., Osberger, M. J., & Boyle, P. (1997). CLARION patient performance: an update on the adult and children's clinical trial. *Scandinavian Audiology*, 47, 45-49.
- Levitt, H. (1997). Digital hearing aids: Past, present, and future. In H. Tobin (Ed.), *Practical Hearing Aid Selection and Fitting* (pp. xi-xxiii). Washington, DC: Department of Veterans Affairs: Rehabilitation and Development Service, Monograph 001.
- Levitt, H., Pickett, J. M., & Houde, R. A. (Eds.) (1980). *Sensory Aids for the Hearing Impaired*. New York: IEEE Press.
- Lynch, M. P., Eilers, R. E., Oller, D. K., Urbano, R. C., & Pero, P. J. (1988). Multisensory narrative tracking by a profoundly

- deaf subject using an electrocutaneous vocoder and a vibrotactile aid. *Journal of Speech and Hearing Research*, 32, 331-338.
- Magner, M. E. (1972). *A Speech Intelligibility Test for Deaf Children*. Northampton, MA: Clarke School for the Deaf.
- McDermott, H. J., Dean, M. R., & Dillon, H. (1999). Control of hearing-aid saturated sound pressure level by frequency-shaped output compression limiting. *Scandinavian Audiology*, 28, 27-38.
- Oller, D. K. (1995). Tactile aids for the hearing impaired: An overview. *Seminars in Hearing*, 16, 289-295.
- Osberger, M. J., Robbins, A. M., Todd, S. L., & Brown, C. J. (1991). Initial findings with a wearable multichannel vibrotactile aid. *American Journal of Otology*, 12(Suppl.), 179-182.
- Peterson, G. E., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech and Hearing Disorders*, 27, 62-70.
- Plant, G. L. (1989a). A comparison of five commercially-available tactile devices. *Australian Journal of Audiology*, 11, 11-19.
- Plant, G. L. (1989b). *COMMTRAC. Modified Connected Discourse Tracking Exercises for Hearing Impaired Adults*. Sydney: National Acoustic Laboratories Central Laboratory.
- Plant, G. L. (1995). Training approaches with tactile aids. *Seminars in Hearing*, 16, 394-403.
- Reed, C. M., & Delhorne, L. A. (1995). Current results of a field study of adult users of tactile aids. *Seminars in Hearing*, 16, 305-315.
- Reed, C. M., Durlach, N. I., Delhorne, L. A., Rabinowitz, W. M., & Grant, K. W. (1989). Research on tactual communication of speech: Ideas, issues, and findings. *Volta Review Monograph*, 91, 65-78.
- Roger, A., Thornton, D., & Phillips, A. J. (1992). A comparative trial of four vibrotactile aids. In: I. Summers (Ed.), *Tactile Aids for the Hearing Impaired* (pp. 231-251). London: Whurr.
- Saunders, F. A. (1985). *Tacticon 1600 Electrocutaneous Vocoder*. Concord, MA: Tacticon Corporation.
- Summers, I. R. (Ed.) (1992). *Tactile Aids for the Hearing Impaired*. London: Whurr.
- Summers, I. R., & Farr, J. (1989). Development of a single-channel tactile aid for the profoundly deaf. In: *Proceedings of Eurospeech '89, Paris* (pp. 706-709). Edinburgh: CEP Consultants.
- Thornton, A. R., & Raffin, M. J. (1978). Speech discrimination scores modelled as a binomial variable. *Journal of Speech and Hearing Research*, 21, 507-518.
- Waldstein, R. S., & Boothroyd, A. (1995). Comparison of two multichannel tactile devices as supplements to speechreading in a postlingually deafened adult. *Ear and Hearing*, 16, 198-208.
- Weisenberger, J. M. (1989). Evaluation of the Siemens minifonator vibrotactile aid. *Journal of Speech and Hearing Research*, 32, 24-32.
- Whitford, L. A., Seligman, P. M., Everingham, C., Antogenelli, T., Skok, L., Hollow, R., Plant, K., Gerin, E. S., Staller, S. J., McDermott, H. J., Gibson, W. P. R., & Clark, G. M. (1995). Evaluation of the Nucleus Spectra 22 processor and new speech processing strategy (SPEAK) in postlinguistically deafened adults. *Acta Oto-Laryngologica*, 115, 629-637.

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Galvin, Karyn L.;Mavrias, Gina;Moore, Alessandra;Cowan, Robert S. C.;Blamery, Peter J.;Clark, Graeme M.

Title:

A comparison of Tactaid II+ and Tactaid 7 use by adults with a profound hearing impairment

Date:

1999

Citation:

Galvin, K. L., Mavrias, G., Moore, A., Cowan, R. S. C., Blamery, P. J., & Clark, G. M. (1999). A comparison of Tactaid II + and Tactaid 7 use by adults with a profound hearing impairment. *Ear and Hearing*, December, 20, 471-482.

Persistent Link:

<http://hdl.handle.net/11343/27512>